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ORIGINAL ARTICLE

Assessment of Weathering Pattern in Laterite Associated Soils of Nellore Schist Belt, Andhra Pradesh, India

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ABSTRACT

Weathering is extensively utilized for pedospheric data that helps in understanding genetic relationships and soil characteristics to address environmental challenges. In this study, six representative soil profiles from the Nellore schist belt were analyzed for their morphology, physical properties, chemical makeup, and elemental composition. These soils, located on the rolling peneplains of the Somasila project, exhibit a red to dark reddish-brown matrix with clay-rich argillic/cambic horizons, characterized by an Ap-Bt/Bw sequence along with compact ferruginous gravels and laterite. The depth trends of redness ratings and CIELab values in moist conditions are significantly higher than in dry conditions, but they show a decreasing trend with profile depth. Additionally, am demonstrates a strong positive correlation with redness rating (Torrent) at 0.73** in moist conditions and 0.83** in dry conditions, while showing a moderate positive correlation with clay at 0.57*. In Venkateswapalem (P2) and Venkatachalam (P3), there is an increase in clay by more than 1.2 times in the B horizons, indicating argillic characteristics, yet the silt to clay ratio exceeds 0.15, suggesting a young soil with a high degree of weathering potential. These soils are slightly acidic to neutral, exhibiting low organic carbon, total nitrogen, cation exchange capacity, and exchangeable bases, resulting in a base saturation of over 60%, categorizing them under the subgroups of Inceptisols and Alfisols. The high molar ratios of Si-Al-Fe indicate a non-lateritic nature; however, the ternary diagram along with IOL/CIA suggests that these soils are kaolinitized with an advanced stage of laterization, reflecting significant base loss and accumulation of Fe-Al oxides. Correlation results revealed a strong significant relationship between Kornberg-A and PI (r=0.92**), as well as a high positive correlation between CIA and WI (r=0.86**). The findings indicate that two clusters are classified within the subgroups of Entisols, Inceptisols, and Alfisols,

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exhibiting a high degree of weathering influenced by topographic position, which directly affects weathering intensities.

KEYWORDS

• Laterite • Weathering indices • Molar ratio • K mean clustering • Correlation • Elemental composition • Ternary diagram

INTRODUCTION

The evolution of soil is contingent upon the balance between soil production and denudation[1,2] and is mainly investigated at the pedon or catena scale.[3,4] In eroding landscapes, the topography influences soil erosion, which determines both soil thickness and the residence time of soil particles[5] as well as vertical fluxes that clarify spatial variations in soil properties.[6] Studies examining the effect of slope gradient on soil thickness, weathering degrees, and rates at the hillslope scale have yielded diverse results.[7] Conversely, the relationship between slope and weathering degree and rate has indicated both a decrease[8] and an increase[9] in weathering degrees with a higher slope gradient. The weathering rate is the mass that is chemically altered or removed over time[10] and offers information on two aspects: (i) the degree of weathering and (ii) the time frame during which weathering reactions have occurred.[11,12]

Over 30 chemical weathering indices have been proposed to measure the weathering degree of soils based on their chemical and/or mineralogical composition.[13] In our multiproxy approach, we incorporate 14 of these indices with a key assumption derived from the relative abundance of chemical elements and/or their oxidation state.[14] As weathering progresses, iron in primary minerals is released and oxidized, which increases the ratio of oxidized iron (Fed) to total iron (Fet), ranging from 0 for fresh material to 1 for fully weathered material.[15,16] The CIA indicates the degree of weathering as the ratio of a conservative oxide, Al_2O_3, to the total of the major oxides.[17,18] This includes the Ruxton ratio (R), which compares the loss of silica to the loss of all elements, assuming that sesquioxides (Al_2O_3, Fe_2O_3, and TiO_2) remain immobile during weathering,[19] and the Chemical Index of Weathering (CIW), which does not include K_2O in the calculation as it does not account for the Al linked with K-feldspar.[20,21] The Weathering Index of Parker (WIP) is based on the percentage enrichment of alkali and alkaline earth metals (Na, K, Ca, and Mg) in the horizon and considers their varying mobilities based on oxygen binding strength.[22,23] The Plagioclase Index of Alteration (PIA) is used to monitor the weathering of plagioclase[24] and to determine the rate at which parent materials weather into their respective weathered products.[25]

The examination of soils is part of the Nellore Schist Belt (NSB) located around Gudur and Kavali in the laterite belt of Nellore District, Andhra Pradesh. This region plays a crucial role in the Precambrian history of Peninsular India, consisting of high-grade metamorphics, a volcanic sedimentary sequence, migmatites, granites, pegmatites, and several basic igneous intrusions known as the Kandra igneous complex,[26] also referred to as the Kandra ophiolite complex.[27] Laterite and lateritic soils are specific to India and some tropical countries with a periodically moist climate. In India, they cover an area of about 248,000 square kilometers.[28] These soils are present in the districts of Srikakulam, Visakhapatnam, East Godavari, Nellore, and Medak in Andhra Pradesh. In the Medak district, laterite soils occupy 82,869 hectares, with 61,793 hectares (56.6%) in the Zaheerabad area, followed by Sadasivapet.[29] The general characteristics of laterite-associated soils have been reported in Kerala,[30] Nellore district of Andhra Pradesh,[31] and Medak district.[32] Silica was used as a constant to create the geochemical mass balance sheet of laterite-associated soils in the Somasila project.[33] A notable characteristic of these laterite soils is the strong chroma and redder hue due to clay accumulation, along with a relatively minor accumulation of Fe and Al sesquioxides in the B horizon, where the silica to sesquioxide ratio is less than 2.[34] Research on the weathering of these soils is limited. Thus, the main aims of this paper were to determine the elemental composition and evaluate the weathering intensity of laterite-associated soils using different weathering indices. The results of this study will provide information on weathering of lateritic soils for sustainable management for rainfed production of millets in the region.

MATERIALS AND METHODS

Study area

The study area is situated within the Somasila and Telugu Ganga project region in the Nellore district of Andhra Pradesh. This locale is positioned between 14°05′N latitude and 79°08′E longitude (Figure 1) at an elevation of 50 meters above mean sea level (MSL). The topography is characterized by undulating to rolling peneplains, featuring laterite exposures and soils that range from red to dark reddish-brown. The climate is classified as semiarid monsoonic, exhibiting distinct seasons: the southwest monsoon (June to September), northeast monsoon (October to December), winter (January to February), and the hot summer months (March to May). Consequently, the district's climate is predominantly dry and healthful. Typically, April, May, and June are the hottest months, with a peak temperature of 41.2°C recorded in May, while November, December, and January experience a minimum temperature of 21.9°C during the years 2013-2014. The average rainfall for the district is 1080.5 mm; however, only 758.9 mm was recorded during 2013-2014. The northeast monsoon contributed 369.6 mm to this total. The area receives 61 percent of its total normal rainfall (1080 mm) during the northeast monsoon, while 31 percent is attributed to the southwest monsoon, resulting in a total rainfall decrease to 848 mm in 2013 and 758 mm in 2014.[33]

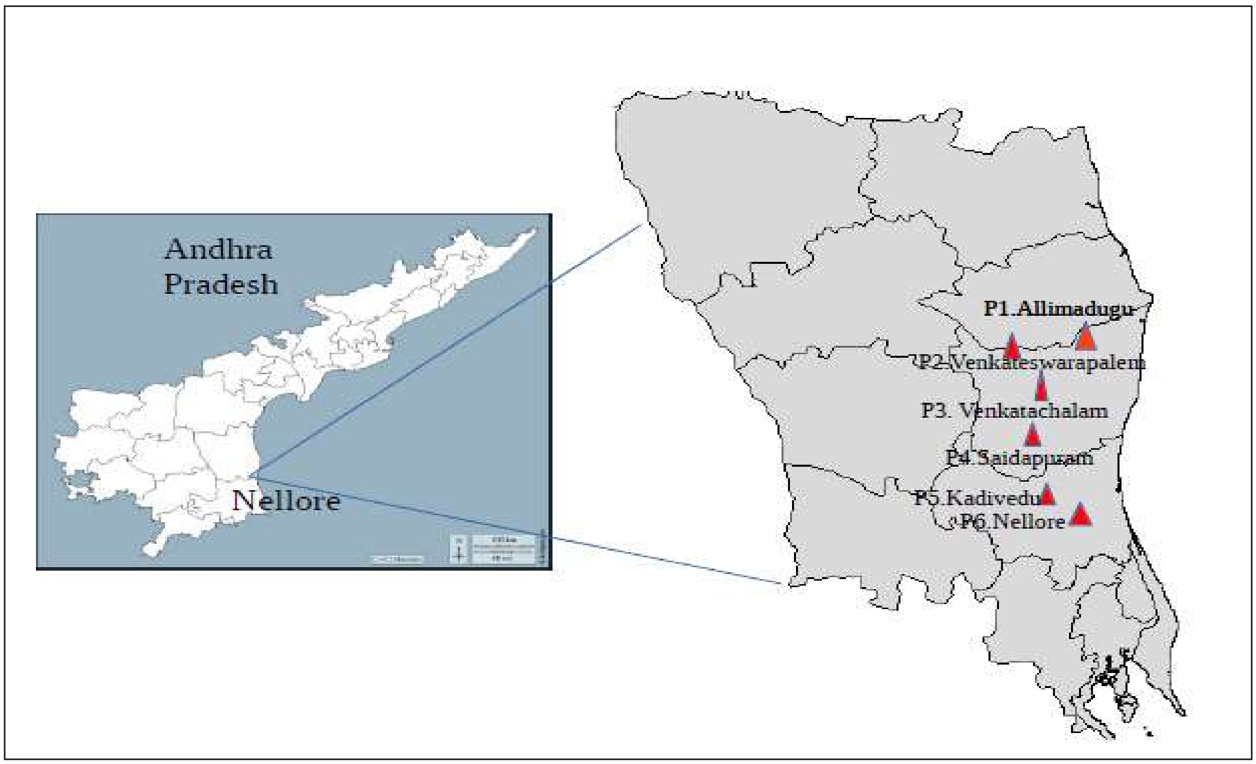

Figure 1: Location map of Nellore with laterite associated soil profile sites

Drawing upon the existing literature and the geological framework of the laterite region in Nellore district, it is observed that the robust crust of gravelly laterite has been partially worn away by rills and gullies. Two distinct layers of pisolitic nodules have been identified: (1) a loose and less compacted zone of gravelly iron concretions, measuring between 10 to 25 cm in thickness, and (2) a compacted and solid layer characterized by regularly spaced nodules, which are cemented by a red clayey matrix, exhibiting an uncertain spatial relationship with the coastal laterite of the Miocene – Pliocene surface.[35,36] For this study, six representative laterite-associated soils were selected from Allimadugu (P1), Venkateshswarapalem (P2), Venkatachalam (P3), Saidapuram (P4), Kadivedu (P5), and Nellore (P6).

The Munsell soil colour chart was used to describe the soil colors and coverted to derive three redness ratings[37,38,39] and CIE Lab values[40] as given below:

Redness rating	Formulae	Reference
Buntley and Westin	RR_{BW}= H * C where C is chroma and H determined accordingto hue (10R = 7, 2.5YR = 6, 5YR = 5, 7.5YR = 4, 10YR = 3, 2.5Y = 2, 5Y = 1).	[37]
Hurst	RR_H = H * V / C where C is chroma, V is value, and H is determinedaccording to hue (5R = 5, 7.5R = 7.5, 10R = 10,2.5YR = 12.5, 5YR = 15, 7.5YR = 17.5, 10YR= 20).	[38]
Torrent	RRT2 = (10-H) * C / V (4) where C is chroma, V is value, and H the figurepreceding YR in the Munsell hue, with 10R = 0.	[39]
CIE Lab system	L* is the luminance (grade of lightness from 0-100), a* quantifies the components red (>0) vs. green (<0)and b* yellow (>0) to blue (<0).	[40]

Laboratory Analysis

The fine earth fraction from air-dried soil samples of each horizon was utilized for the analysis of physical, chemical, and elemental composition according to standard procedures. The international pipette method was employed to assess particle size analysis, preceded by a treatment with hydrogen peroxide (H_2O_2) to eliminate organic matter and dispersion achieved by shaking with sodium hexametaphosphate.[41] The Keen box (Rackzowski box) method was implemented to evaluate physical characteristics such as bulk density, porosity, sticky point, and water holding capacity of the soil using this technique.[42] The pH (1:2.5), Organic carbon (OC, Walkley Black), Cation exchange capacity (CEC), and exchangeable bases (1N neutral ammonium acetate) along with percent base saturation were calculated as the sum of bases/CEC*100.[43] Free iron compounds (Fe_d), encompassing both poorly and well-crystalline forms, were extracted using a dithionate-citrate-bicarbonate (DCB) solution.[44] Elemental analysis was performed on the 1mm soil fraction through Na_2CO_3 fusion for all elements except sodium, which was digested using triacid and measured by Atomic Absorption Spectrophotometer (Hitachi model).[45] Silica and R_2O_3 were determined gravimetrically.The weighted mean of the profile was determined as follows: weighted mean (Ŵ) equals the soil variable value multiplied by the horizon thickness, then divided by the total thickness of the profile. The elemental composition was then utilized to calculate molar ratios and weathering indices as outlined below. Molar concentrations were estimated by dividing the elemental concentrations with atomic weight of the elements. In this work, the following indicators of weathering were analyzed:

Molar ratios / weathering indices	Formulae	Reference
silt:clay ratio (SCR)	silt/clay	Van Wambeke (1962)[46]
silica:sesiquioxide ratio (SSR)	$SiO_2/R_2O_{3(Al2O3+Fe2O3+TiO2)}$	Singh, Parkash, and Singhvi (1998)[47]
Silica:aluminium oxide	SiO_2/Al_2O_3	
Silica:Iron oxide ratio	SiO_2/Fe_2O_3	Birkeland (1984)[48]
Aluminium oxide to Iron oxide ratio	Al_2O_3/Fe_2O_3	
Modified Potential Weathering Index (MPWI)	$(Na_2O+K_2O+CaO+MgO)$/ X 100 $(Na_2O+K_2O+CaO+MgO+SiO_2+Al_2O_3+Fe_2O_3)$	Vogel (1975)[49]
Parker index	PI= $2Na_2O/0.35+MgO/0.90+2K_2O/0.25+CaO/0.70$ X100	Parker (1970)[22]
chemical index of Alteration (CIA)	CIA=Al_2O_3X100/ $(Al_2O_3+CaO+Na_2O+K_2O)$	Nesbitt and Young (1989)[17]

table cont...

Molar ratios / weathering indices	Formulae	Reference
Chemical index of weathering(CIW)	$CIW = Al_2O_3 X100 / (Al_2O_3+CaO+Na_2O)$	Harnois (1988)[21]
Korenberg index A	$(SiO_2+CaO+K_2O+Na_2O)/(SiO_2+Al_2O_3+CaO+K_2O+Na_2O)$	Nesbitt and Young (1989)[17]
Korenberg index A	$(CaO+K_2O+Na_2O)/(Al_2O_3+CaO+K_2O+Na_2O)$	
Weathering index (WI)	$(Al_2O_3+Fe_2O_3)/(Na_2O+K_2O)$	Jackson (1975)[50]
Dithionite iron to total iron	Fe_d/Fe_t	Duchaufour 1983 [51]
Index of laterization (IOL)	$100 X[(Al_2O_3+Fe_2O_3(T))/(SiO2+Al_2O_3+Fe_2O_3(T))$	
Mafic index of alteration (MIA)-(O)	$100 X[(Al_2O_3+Fe_2O_3(T))/(Al_2O_3+Fe_2O_3(T)+MgO+CaO+Na2O+K2O))$	Babechuk *et al.* (2014)[52]
Mafic index of alteration (MIA)-(R)	$100 x [(Al_2O_3)/(Al_2O_3+Fe_2O_3(T+MgO+CaO+Na_2O+K_2O)]$	

Statistical analysis

The analytical data acquired during the study were subjected to descriptive statistical analysis, correlation and regression, two-sample t-test, one-way Analysis of Variance (ANOVA) with Tukey's test, and K-means clustering utilizing Stat Blue, Stat Kingdom, and Microsoft Excel to evaluate the variation between elemental compositions and weathering indices at a 5% level of probability. The coefficient of variation (CV) was classified according to the criteria established by Wilding and Dress[53] as low (CV < 15–35%), medium (CV = 15–35%), and high (CV > 35%), respectively. The guideline for interpreting the correlation coefficient was based on Mukaka[54] as outlined below.

Size of Correlation	Interpretation
.90 to 1.00 (−.90 to −1.00)	Very high positive (negative) correlation
.70 to .90 (−.70 to −.90)	High positive (negative) correlation
.50 to .70 (−.50 to −.70)	Moderate positive (negative) correlation
.30 to .50 (−.30 to −.50)	Low positive (negative) correlation
.00 to .30 (.00 to −.30)	negligible correlation

RESULTS AND DISCUSSION

Soil Morphology

Table 1 illustrates the morphology of various soils. The moderately deep and well-drained Allimadugu soil (P1) features an AP-B/A-Bt horizon sequence characterized by a distinctly smooth to wavy boundary, maintaining slightly acidic conditions throughout its depth. The Ap horizon, exhibiting a dark yellowish brown (10YR4/4, moist) to yellowish brown (10YR5/6) coloration, measures 9 cm in thickness and possesses a loamy texture. This soil contains 5% quartzitic ferruginous gravel, presenting a fine to medium subangular blocky structure with a slightly hard consistency when dry. In contrast, the moderately deep and neutral Venkateswara palem displays a color gradient from red (2.5YR4/8, moist to 5/6, dry) to dark red (2.5YR3/6, moist to 4/5, dry), featuring argillic B horizons with patchy clay films, which transition dramatically to yellowish red (5YR4/6, moist) and reddish brown (5YR4/6, dry) at the Bt4 horizon. Below 92 cm, this soil reveals a murram layer interspersed with ferruginous gravel. The Venkatachalam (P3) soil is shallow, showcasing red argillic B horizons (2.5YR3/6 to 2.5YR4/6) and 10% moderate ferruginous gravels, while Saidapuram (P4) boasts an 11 cm thick Ap horizon that shifts from strong brown (7.5YR5/6, moist) to reddish brown (7.5YR6/6, dry), altering in the argillic B horizons to yellowish red (5YR 4/4 to 5/6) and dark reddish brown (YR3/4, moist). Both Kadivedu (P5) and Nellore soil (P6) are notably shallow, featuring an Ap-Bw horizon sequence with an Ap horizon that ranges from strong brown to reddish yellow (7.5YR) and a cambic horizon displaying a reddish brown to yellowish red matrix, accompanied by compact ferruginous gravels and laterite. All these soils exhibit a neutral reaction with distinctly smooth to wavy boundaries.

Table 1: Morphology of soils

Depth (cm)	Horizon	colour		texture	structure	consistency			coarse fragments (%)	porosity	cutans	roots	pH	boundary
		moist	dry			wet	moist	dry						
P1.Allimadugu														
0-9	Ap	10YR4/4	10YR5/6	L	f1gr	so,po	fr	sh	5%quartz and ferrugenous gravel	f,f,		ff	6.5	cs
9-21	B/A	7.5YR5/8	7.5YR6/6	L	m2sbk	so,po	fr	sh		ff		ff	6.3	cs
21-38	Bt	7.5YR4/5	7.5YR5/8	L	m2sbk	ss,sp	fr	sh		f,f,	patchy, thin	f,f	6.45	cw
38-65	compact ferrugenous murram layer,below 65cmplinthite through which root penetration isdifficult													
P2.Venkateswara Palem														
0-15	Ap	2.5YR4/8	2.5YR5/6	Cl	f1sbk	ss,sp	fr	sh		f,f,		f,f	6.75	cs
15-31	B/A	2.5YR4/8	2.5YR5/6	Cl	m2sbk	ss,sp	fr	sh	55 iron and quartz coarse fragments	f,f,	few patchy thin	c,f	6.9	cs
31-53	Bt2	2.5YR3/6	2.5YR4/5	Cl	m2sbk	ss,sp	fr	sh		f,f,		c,f	6.75	cs
53-68	Bt3	2.5YR3/6	2.5YR4/5	Sicl	m2sbk	s,p	fi	h	5% iron and quartz fragments	f,f,		c,f	6.5	cs
68-92	Bt4	5YR4/6	5YR4/4	Cl	m2sbk	s,p	fi	h		f,f,		f,f	6.7	cw
Below 92 cm quartz murram layer mixed with ferrugenous gravel with negligible amounts of soil														
P3.Venkatachalam														
0-10	Ap	7.5YR4/5	7.5YR6/4	Sl	f1sbk	so,po	fr	sh	(10%) moderate ferrugenous concretions	f,f,		f,f	6.65	cs
10-22	Bt1	2.5YR4/5	2.5YR5/6	Scl	m2sbk	ss,sp	fr	sh		f,f,	thin patchy	f,f	6.85	cs
22-41	Bt2	2.5YR3/6	2.5YR4/6	Gsc	m2sbk	s,p	fr	sh		f,f,	thin patchy	f,f	6.75	cw
compact ferrugenous murram layer,below 65cmplinthite through which root penetration isdifficult														
P4.Saidapuram														
0-11	Ap	7.5YR4/4	7.5YR5/6	L	f1gr	ss,sp	fr	sh		f,f,		f,f	6.65	cs
11-26	Bw1	5YR4/8	5YR5/6	Cl	m2sbk	ss,sp	fr	sh		f,f,	Thin , patchy	f,f	6.95	cs
26-36	Bw2	5YR3/4	5YR4/4	Gcl	m2abk	ss,sp	fr	sh		f,f,	thin patchy	f,f	7	cw
ferrugenous and quartzite gravelly layer. Roots can penetrate														
P5.Kadivedu														
0-13	Ap	7.5YR5/8	7.5YR6/6	L	f1gr	ss,sp	fr	sh		f,f,		f,f	7	cs
13-456	Bw	5YR3/5	5YR4/6	Gcl	m2sbk	ss,sp	fr	sh		f,f,		f,f	6.85	cs
compact alyer of ferrugenous murram layer and below laterite														
P6.Nellore														
0-10	Ap	7.5YR5/6	7.5YR6/6	Sl	figr	so,po	fr	sh		f,f,		f,f	6.7	
10-30	Bw	7.5YR5/8	7.5YR5/6	Gl	fisbk	ss,sp	fr	sh		f,f,		f,f	6.35	
compact ferrugenous gravelly layer and below laterite														

Redness rating and CIE Lab system

The analysis of three modes of redness rating is encapsulated in **Table 2**. The rrBw illustrates a trend of increasing depth (from 12 to 20 for moist; 18 to 32 for dry) with a weighted mean of 21.89 under moist conditions and 20.79 under dry in P1. Conversely, the red to dark red B horizons present rrbw values ranging from 30 to 36 (moist) and 20 to 30, with weighted means of 38.48 (moist) and 29.11 (dry). The weighted mean for rrbw under moist conditions fluctuates from 26.98 (P5) to 29.62 (P3), while dry values extend from 24 (P6) to 32.28. In P3, the rrbw exhibits increasing depth trends from 20 to 36 (moist) and 24 to 36 (dry). Similar trends are noted in P6, albeit with variability in other soils. The rrH indicates increasing trends in P1 and P6, remains fairly uniform in P2, but is erratic in other soils. The weighted mean ranges from 25.85 (P5) to 25.67 (P6) under moist conditions, while dry values range from 21.09 (P5) to 12.7 (P3). Moist values consistently surpass dry values across all these systems. The rrT value is zero for the 10YR hue in

Ap (P1), with a weighted mean of 2.66 (moist) to 2.58 (dry). In P2, the rrt values in redder B horizons range from 15 to 3.75 (Ŵ=8.52), while dry values are at 9.38 (Ŵ=7.8). The red to dark red with a 2.5 YR hue is correlated with hematite content under well-oxidized conditions, while the 5YR/7.5YR hue indicates lower Fe oxide content due to erosion or a younger masking red color, and the 10YR hue is associated with lepidocrocite. CIE Lab (moist) reveals decreasing depth trends across all profiles, except in P1, where values range from 41.2 to 51.6 (Ŵ=49.14). The a and b values are erratic, with a weighted mean of 15 for a and 29.95 for b in P1. The L values in P2 decline from 41.2 in Ap to 30.8 in argillic B horizons, with similar depth trends for a (27.2 to 22.2) and b values (35.8 to 26). The a*1 values range from 0.57 (Bt4) to 0.75 (Ap), with a weighted mean of 0.75, while b*1 values range from 1.17 (Bt) to 1.75 (Bt4), with a weighted mean of 1.37. Remarkably, dry CIELab values are elevated compared to moist values, with a weighted mean for L of 57.3 (P3) > 54.97 (P6) > 54.79 (P1). For a, the weighted means are 18.46 (P2) > 17.5 (P3) > 16.09 (P5), and for b*1, it exceeds 2 in P1, P4, P5, and P6.

Table 2: Conversion of Munsell colour notation to redness rating and CIE Lab values in soils of Nellore

Horizon	colour		Rrbw		hurst		CIE										rrt	
							Lm	am	bm	am*1	bm*1	Ld	ad	bd	ad*1	bd*1		
	moist	dry	moist	dry	moist	dry	moist					Dry					moist	dry
P1.Allimadugu																		
Ap	10YR4/4	10YR5/6	12	18	20	24	41.2	6.6	26	0.25	3.93	51.6	8.8	38.9	0.22	4.42	0	0
B/A	7.5YR5/8	7.5YR6/6	32	24	28	17.5	51.6	17.1	47	0.36	2.74	61.7	12.5	34.4	0.36	2.75	4	2.5
Bw	7.5YR4/5	7.5YR5/8	20	32	21.87	28	51.6	12	28.7	0.41	2.39	51.6	17.1	47	0.36	2.75	3.13	4
Ŵ			21.89	20.79	22.53	20.16	49.14	15.91	29.95	0.36	2.87	54.79	14.98	29.02	0.33	2.75	2.66	2.58
P2.Venkateswara Palem																		
Ap	2.5YR4/8	2.5YR5/6	48	36	25	15	41.2	27.2	35.8	0.75	1.31	51.6	23.5	31.1	0.75	1.32	15	9
B/A	2.5YR4/8	2.5YR5/6	48	36	25	15	41.2	27.2	35.8	0.75	1.31	51.6	23.5	31.1	0.75	1.32	15	9
Bt2	2.5YR3/6	2.5YR4/5	36	30	25	15.62	30.8	22.2	26	0.85	1.17	41.2	18.1	21.8	0.83	1.2	3.75	9.38
Bt3	2.5YR3/6	2.5YR4/5	36	30	25	15.62	30.8	22.2	26	0.85	1.17	41.2	18.1	21.8	0.83	1.2	3.75	9.38
Bt4	5YR4/6	5YR4/4	30	20	22.5	15	41.2	17.5	30.7	0.57	1.75	41.2	12.5	20.8	0.6	1.66	7.5	4
Ŵ			38.48	29.41	24.35	15.25	37.02	22.66	30.53	0.75	1.37	44.7	18.46	24.67	0.75	1.36	8.52	7.85
P3.Venkatachalam																		
Ap	7.5YR4/5	7.5YR6/4	20	24	21.87	11.66	51.6	12	28.7	0.41	2.39	61.7	8.5	22.5	0.37	2.65	3.13	1.67
Bt1	2.5YR4/5	2.5YR5/6	30	36	15.62	15	41.2	18.1	21.8	0.83	1.2	51.6	23.5	31.1	0.75	1.32	9.38	9
Bt2	2.5YR3/6	2.5YR6/6	36	36	25	12.5	30.8	22.2	26	0.85	1.17	61.7	19.4	26.1	0.74	1.35	15	7.5
Ŵ			29.6	32.2	20.9	12.7	37.9	18.07	24.82	0.72	1.4	57.3	17.5	26.05	0.64	1.61	10.2	6.3
P4.Saidapuram																		
Ap	7.5YR4/4	7.5YR5/6	16	24	17.5	21	41.2	10	23.6	0.42	2.36	51.6	13.4	34.9	0.38	2.6	2.5	3
Bw1	5YR4/8	5YR5/6	40	30	30	18	41.2	22.2	41.1	0.54	1.85	51.6	16.8	31.1	0.54	1.85	10	6
Bw2	5YR3/4	5YR4/4	20	20	20	15	30.8	12.7	19.6	0.64	1.54	41.2	12.5	20.8	0.6	1.66	6.67	5
Ŵ			27.11	25.38	23.4	18.08	38.31	15.8	29.7	0.53	1.92	48.71	14.56	29.4	0.5	2.03	6.78	4.8
P5.Kadivedu																		
Ap	7.5YR5/8	7.5YR6/6	32	24	28	17.5	51.6	17.1	47	0.36	2.74	61.7	12.5	34.4	0.36	2.75	4	2.5
Bw	5YR3/5	5YR4/6	25	30	25	22.5	30.8	12.7	19.6	0.64	1.54	41.2	17.5	30.7	0.57	1.75	8.33	5
Ŵ			26.98	28.3	25.85	21.09	36.68	13.94	27.34	0.57	1.88	46.99	16.09	31.75	0.51	2.04	7.11	4.29
P6.Nellore																		
Ap	7.5YR5/6	7.5YR6/6	24	24	21	17.5	51.6	13.4	34.9	0.38	2.6	61.7	12.5	34.4	0.36	2.75	3	2.5
Bw	7.5YR5/8	7.5YR5/6	32	24	28	21	51.6	17.1	47	0.36	2.74	51.6	13.4	34.9	0.38	2.6	4	3
Ŵ			29.33	24	25.67	19.83	51.6	15.87	42.97	0.37	2.7	54.97	13.1	34.73	0.38	2.65	3.67	2.83

Physical characteristics of soils

The weighted mean gravel content exceeds 35% in profiles P3, P4, P5, and P6, signifying a notably gravelly particle size.[57] The average coarse sand measures 40.5%, while clay constitutes 24.8%, accompanied by minimal amounts of fine sand (21.2%) and silt (13.5%), which highlights the dominance of quartz and feldspars. In the Venkateshswara Palem profile (P2), the existence of an argillic horizon is validated by an increase in clay content. The clay levels range from 31 to 41 percent in the subsoils of Venkateshswara Palem (P2), and the Venkatachalam (P3) profiles exhibit a gradational rise in clay within the argillic B horizons, increasing by more than 1.2 times from the Ap to the Bt horizons, unlike other soils. A notable trend of increasing silt depth is observed in profiles 1, 3, 5, and 6 (**Table 3**). In the Nellore soil (P6), coarse sand content surpasses 50% with depth, while it diminishes in P3 and P5. The proportions of sand have led to elevated sand-to-silt ratios, with erratic depth trends that suggest variable rates of colluviation across the peneplains of the lateritic belt. The subtle depth trends of bulk density across the profiles indicate consistent weathering rates, with values ranging from 1.22 to 1.67 Mgm^{-3}. Comparable bulk densities have been documented in the soils of the east coast laterite found in Tamil Nadu.[58,59] The silt/clay ratio is elevated in the surface horizon and diminishes with depth in the pedons. This reduction in the silt/clay ratio with depth suggests that the sub-soil horizons are more weathered than the surface horizons. The findings of this study reveal that the majority of the soils possess a silt/clay ratio exceeding 0.15, indicating that these soils are relatively young and exhibit a high degree of weathering potential.[46]

Table 3: Physical chracteristics of soils

Soil series	Depth (cm)	Particle Size distribution(%, <2mm)						Bulk density (Mg/m3)	water holding capacity(%)	pore space(%)	Sticky point(%)	sand/ silt	silt/ clay
		gravel (%)	Coarse sand	find sand	total sand	silt	clay						
1.Allimadugu	0-9	15.2	43.11	23.96	67.07	10.95	21.91	1.22	21.37	52.51	19.18	6.13	0.5
	9-21	16.66	43.66	20.61	64.27	12.84	22.79	1.67	28.9	47.93	20.49	5.01	0.56
	21-38	19.25	50.23	17.28	67.51	12.13	20.23	1.63	23.27	36.91	25.03	5.57	0.6
	Ŵ	17.47	46.47	19.91	66.38	12.07	21.44	1.55	24.6	44.08	22.21	5.52	0.56
2.Venkateshswarapalem	0-15	17.94	23.09	14.76	37.85	16.05	26	1.35	32.71	51.82	24.44	2.36	0.62
	15-31	15.56	34.63	16.7	51.33	12.56	36.08	1.32	34	51.52	25.74	4.09	0.35
	31-53	15.38	32	14.4	46.4	12.09	41.5	1.42	37.61	49.57	27.46	3.84	0.29
	53-68	21.87	30.73	9.87	40.6	27.71	31.61	1.49	28.01	47.29	22.02	1.47	0.88
	68-92	19.07	28.57	14.19	42.76	24.33	32.98	1.53	31.06	42.63	20.41	1.76	0.74
	Ŵ	17.85	29.9	14.07	43.97	18.56	34.2	1.43	32.91	48.09	23.94	2.71	0.57
3.Venkatachalam	0-10	27.93	54.13	26.88	81.01	4.41	14.53	1.47	23.74	48.88	17.64	18.37	0.3
	10-22	65.96	45.64	23.58	69.22	9.3	20.46	1.64	14.74	41.42	19.13	7.44	0.45
	22-41	69.41	36.14	12.88	49.02	16.25	34.71	1.45	35.04	46.33	26.94	3.02	0.47
	Ŵ	58.28	43.31	19.43	62.73	11.33	25.62	1.51	26.34	45.51	22.39	8.06	0.42
4.Saidapuram	0-11	12.93	4.04	20.25	24.29	18.26	21.41	1.57	26.99	45.93	19.1	1.33	0.85
	11-26	64.15	37.93	22.87	60.8	15.32	23.84	1.61	30.95	45.16	21.65	3.97	0.64
	26-36	64.58	41.92	23.95	65.87	9.34	24.71	1.52	35.52	50.76	25.62	7.05	0.38
	Ŵ	46.83	27.52	21.7	49.22	14.3	22.65	1.53	30.02	45.54	21.26	3.82	0.62
5.Kadivedu	0-13	46.13	44.15	24.37	68.52	10.89	20.77	1.61	30.32	47.76	22.04	6.29	0.52
	13-456	72	31.74	26.61	58.35	13.57	28.07	1.59	33.69	46.96	22.57	4.3	0.48
	Ŵ	64.69	35.25	25.98	61.22	12.81	26.01	1.6	32.74	47.19	22.42	4.86	0.49
6.Nellore	0-10	22.53	54.63	28.91	83.54	5.42	11.11	1.65	24.22	45.32	17.09	15.41	0.49
	10-30	47.58	56.27	18.11	74.38	13.41	13.27	1.56	29.67	47.5	23.08	5.55	1.01
	Ŵ	39.23	55.72	21.71	77.43	10.75	12.55	1.59	27.85	46.77	21.08	8.84	0.84

Chemical properties of soils

The soils associated with laterite are slightly acidic (pH 6.3 in P1) to neutral (pH 7.0 in P4/P5) when measured at a 1:2 soil to water ratio, while the pH in 1N KCl is 4.67 in P6 and 5.54 in P2. The pH measured in 1N KCl is significantly lower than that in water due to the increased concentration of protons.[60] The average difference in pH (ΔpH) is 1.58 (6.73 - 5.15 = 1.58), with a variation of 3.18% for pH in water and 7.42% in KCl. The organic carbon content ranges from 0.05 to 0.47%, with a mean of 0.28±0.14% and a high variability (cv of 49.42%). The average cation exchange capacity (CEC) is 8.33±2.36 cmol/kg, showing moderate variability (cv=28.3%), with values ranging from 3.62 to 11.6 cmol(p+)kg^{-1}, indicating an increasing trend with depth. The Kadivedu soil (P5) has a CEC of 11.6 cmol/kg^{-1} in the Bw horizon of P5, while the A horizon of P3 has a value of 3.62 cmol/kg (Table 4). The total nitrogen content ranges from 0.022 to 0.067 percent, showing a decreasing trend with depth, resulting in narrow C/N ratios from 5.56 to 11.08 in P1, P3, and P4, while the remaining soils have values between 2.06 and 5.53. The exchangeable Ca ranges from 1.24 cmol/kg (P3) to 5.26 cmol/kg (P5). Following Ca, Mg is also dominant, with values ranging from 0.64 to 4.28 cmol/kg. All pedons show an increasing trend except for P2, where Mg exhibits irregular depth trends.The ExNa ranges from 0.13 to 0.92 cmol/kg, while potassium levels vary from 0.03 to 0.23 cmol/kg, indicating significant variability (cv over 60%). In P1 and P2, base saturation exhibits a decreasing trend, yet the average remains at 68.3±6.41%, showing low variability (cv of 9.39%). The Ca to Mg ratio is less than 3, which suggests an inhibition of P uptake[61] and a decline in structural stability, leading to surface sealing.[62] This is attributed to the high hydration energy and the larger radius of Mg compared to Ca.[63] These soils display low exchangeable Ca levels (< 2 cmol/kg) in the surface horizons across all soils, but moderate levels in the subsoil horizons. The exchangeable Mg is high (>1 cmol/kg), while exchangeable K is low (< 0.15 cmol/kg) to moderate (0.15 - 0.3 cmol/kg), and Na levels are also low (<0.1 cmol/kg).

Table 4: Chemical properties of soils

Soil series	pH		OC	Total N	C/N	CEC	Ca	Mg	Na	K	Base saturation (%) S
	water (1:2)	1NKCl	(%)			(cmol/kg)					
P1. Allimadugu											
0-9	6.5	4.7	0.4	0.05	7.37	7.04	1.44	1.48	0.31	0.08	75.4
9-21	6.3	4.6	0.34	0.04	7.66	7.93	3.68	1.83	0.31	0.07	74.26
21-38	6.5	4.8	0.26	0.04	6.4	8.92	3.16	3.04	0.3	0.14	74.41
Ŵ	6.44	4.71	0.32	0.04	7.03	8.16	2.92	2.29	0.3	0.1	74.6
P2. Venkateswara Palem											
0-15	6.8	5.4	0.29	0.05	5.53	6.78	2.16	2.46	0.04	0.42	74.92
15-31	6.9	5.6	0.17	0.05	3.69	10.48	3.16	4.28	0.08	0.28	74.37
31-53	6.8	5.5	0.22	0.05	4.75	11.22	3.23	4.08	0.12	0.3	68.82
53-68	6.5	5.6	0.22	0.04	5.05	10.22	2.74	1.85	0.13	0.92	55.17
68-92	6.7	5.6	0.13	0.04	3.83	9.98	3.64	1.52	0.08	0.73	59.83
Ŵ	6.74	5.54	0.2	0.04	4.5	9.88	3.07	2.82	0.09	0.53	66.21
P3. Venkachalam											
0-10	6.7	5.3	0.41	0.06	6.58	3.62	1.24	0.64	0.06	0.31	62.12
10-22	6.9	5.2	0.35	0.04	8.56	6.64	2.64	1.68	0.12	0.4	63.82
22-42	6.8	5	0.34	0.03	11	9.71	3.58	2.34	0.12	0.38	66.12
Ŵ	6.8	5.13	0.36	0.04	9.25	7.38	2.75	1.75	0.11	0.37	64.51
P4. Saidapuram											
0-11	6.7	5	0.47	0.07	6.98	5.52	2.32	0.96	0.03	0.13	62.38
11-26	7	5.4	0.49	0.05	9.04	9.96	3.76	2.96	0.08	0.21	70.38
26-35	7	5.7	0.46	0.04	11	11.06	4.28	3.46	0.23	0.33	75.06
Ŵ	6.91	5.35	0.48	0.06	8.9	8.85	3.44	2.46	0.1	0.22	69.07

					P5. Kadivedu						
0-13	7	4.8	0.21	0.06	3.31	7.39	3.12	1.66	0.1	0.3	70.05
13-46	6.9	5.2	0.15	0.04	3.51	11.56	5.26	2.88	0.13	0.45	75.43
Ŵ	6.93	5.09	0.17	0.05	3.45	10.38	4.66	2.54	0.12	0.41	73.91
					P6. Nellore						
0-10	6.7	4.6	0.05	0.03	2.06	4.63	1.86	0.68	0.07	0.35	63.77
10-39	6.4	4.7	0.05	0.02	2.44	7.24	2.48	1.64	0.12	0.38	63
Ŵ	6.48	4.67	0.05	0.02	2.34	6.57	2.32	1.39	0.1	0.37	63.2
mean	6.73	5.15	0.28	0.05	6.04	8.33	2.99	2.19	0.13	0.34	68.3
sd	0.21	0.38	0.14	0.01	2.72	2.36	1	1.08	0.09	0.21	6.41
cv(%)	3.18	7.42	49.42	27.76	45.1	28.38	33.6	49.1	67.35	62.06	9.39

Table 5 shows the relationship between color components and the chosen soil properties. The redness rating for moist (rrBW) shows a very strong positive correlation with am (r=0.99**) and a high positive correlation with ad*1 (r=0.73**), rrTm (0.77**), rrTd (0.76*8), and ad (0.71**), along with a moderate positive correlation with rrbwd (0.62**). The clay exhibits a low positive correlation with rrBW (0.5*) and a high negative correlation with bd*1 (-0.72**). In dry conditions, this index demonstrates a very high positive correlation with ad (0.91**) and a moderate positive correlation with am, a*1, ad*1, rrTm, while showing a high positive correlation with rrTd. Under moist conditions, the redness rating (hurst-rrHm) has a low positive correlation with rrHd, bm, and bd. In dry conditions, rrHd displays a moderate negative correlation with pH (-0.58*) and a low negative correlation with Fet (-0.49*), rrTm (-0.49*), and rrTd (-0.43*). There is a high positive correlation between rrHd and bd (0.86**). Within the CIE Lab system, Lm has a moderate positive correlation with sand (0.56*) but a high negative correlation with clay (-0.74**) and a moderate correlation with CEC (-0.69**). The am shows a high positive correlation with rrTm (0.73**) and rrTd (0.83**) but a moderate positive correlation with clay (0.57*). The bm has a low positive correlation with Ld (0.44*), while bd has a low negative correlation with clay, Fet, and pH. Both am*1 and ad*1 have positive correlations with rrTm, rrTd, clay, Fet, and CEC. The bm*1 and bd*1 show negative correlations with clay, CEC, pH, and Fet. Additionally, rrTd has a positive correlation with clay and CEC. The study of relationships shows how landscape position affects soil texture and organic carbon content across a large geographic area, while there is no significant connection between color components and organic matter.[55]

Elemental composition of soils

Table 6 indicates that SiO_2 is the most prevalent, with values ranging from 57.36 to 76.50%, consistently above 60% as depth decreases in the profiles of Allimadugu (P1), Venkateswara Palem (P2), and Nellore (P6), while showing irregular patterns in P3 and P4. The Weighted mean SiO_2 content exceeds 60% across all soils, peaking at 73.84% in P1, followed by 69.33% in P2 and 65.01% in P5. Al_2O_3 shows a gradual increase, ranging from 12.71 to 26.51% in P4, P5, and P6, with weighted averages of 20.99% in P5, 20.92% in P3, and 18.08% in P4. The Fe_2O_3 content varies from 9.75 to 15.75%, with a weighted average of 13.96% in P3. Overall, Fe_2O_3 displays increasing trends with depth, similar to clay. These soils contain CaO levels between 0.15 and 0.84% and MgO levels from 0.12 to 0.96%, with K_2O contents below 0.4%, particularly low at 0.093 to 0.006% in P2 (Table 6). The Na_2O content ranges from 0.47 to 4.57%, showing irregular depth trends in P1 and P2. MnO varies from 0.02 to 0.70% and follows similar trends to free Fe_2O_3 (3.44 to 7.84%) and CuO (60 to 930 mg/kg), with low average Cu/Zn values (3.19), suggesting that the soils formed in a well-oxidizing environment.[64]

Table 5: Correlations between colour components versus selected soil properties

colour components versus soil variables	rrbwm	rrbwd	rrHm	rrHd	Lm	am	bm	am*1	bm*1	Ld	ad	bd	ad*1	bd*1	rrTm	rrTd	sand	silt	clay	OC	CEC	pH	FeT	Fed
rr_{bwm}	1																							
rr_{bwd}	0.62**	1																						
rr_{Hm}	0.23	0.3	1																					
rr_{Hd}	-0.51*	-0.09	0.48*	1																				
Lm	-0.24	-0.17	0.31	0.37	1																			
Am	0.99**	0.65**	0.19	-0.56*	-0.31	1																		
Bm	0.44*	-0.04	0.47*	-0.01	0.59*	0.34	1																	
am*1	0.64**	0.65**	-0.16	-0.57*	-0.74**	0.73**	-0.36	1																
am*1	-0.64**	-0.65**	0.07	0.55*	0.64**	-0.72**	0.31	-0.95**	1															
Ld	-0.05	0.09	0.05	-0.1	0.62**	-0.08	0.44*	-0.39	0.40*	1														
Ad	0.71**	0.92**	0.14	-0.14	-0.32	0.73**	-0.07	0.76**	-0.74**	-0.17	1													
Bd	-0.33	0.14	0.46*	0.86**	0.62**	-0.39	0.22	-0.58*	0.57*	0.34	0.03	1												
ad*1	0.73**	0.60**	-0.14	-0.61**	-0.71**	0.80**	-0.25	0.98**	-0.94**	-0.43	0.74	-0.62	1											
bd*1	-0.72**	-0.60**	0.05	0.60**	0.60**	-0.78**	0.17	-0.92**	0.99**	0.39	-0.71	0.61	-0.94**	1										
rr_{Tm}	0.77**	0.67**	0.01	-0.49*	-0.37	0.76**	0.07	0.66**	-0.69**	0.03	0.73	-0.28	0.66**	-0.70**	1									
rr_{Td}	0.76**	0.77**	0.01	-0.43*	-0.58*	0.83**	-0.17	0.94**	-0.90**	-0.36	0.88	-0.38	0.95**	-0.89**	0.66**	1								
sand	-0.33	-0.24	0.12	0.14	0.56*	-0.39	0.24	-0.48*	0.47*	0.44*	-0.38	0.26	-0.51*	0.46*	-0.32	-0.48*	1							
silt	0.31	0.09	0.12	-0.03	-0.43	0.35	-0.05	0.36	-0.35	-0.51	0.23	-0.25	0.41	-0.38	0.17	0.36	-0.76	1						
Clay	0.50*	0.37	0.06	-0.29	-0.74**	0.57*	-0.29	0.73**	-0.65**	-0.53**	0.48*	-0.45*	0.75**	-0.63**	0.46*	0.67*	-0.66**	0.52*	1					
OC	-0.29	-0.03	-0.2	-0.03	-0.18	-0.23	-0.37	-0.02	0.04	0.07	-0.11	-0.01	-0.09	0.12	0	-0.06	-0.14	-0.1	-0.03	1				
CEC	0.35	0.22	0.3	0	-0.69**	0.37	-0.22	0.54*	-0.54*	-0.70**	0.37	-0.29	0.55*	-0.53*	0.35	0.51*	-0.35	0.44*	0.77**	-0.11	1			
Ph	0.38	0.13	-0.31	-0.58*	-0.39	0.36	-0.01	0.39	-0.45*	0.01	0.23	-0.48*	0.40*	-0.47*	0.53*	0.32	-0.08	-0.19	0.26	0.2	0.27	1		
Fe_T	0.33	0.11	-0.08	-0.49*	-0.34	0.37	0.11	0.41*	-0.37	0.06	0.17	-0.41*	0.40*	-0.42*	0.29	0.36	0.1	-0.04	0.12	0.14	0.24	0.52*	1	
Fe_d	0.15	-0.07	0.04	-0.15	-0.11	0.08	0.26	-0.03	-0.09	0.09	-0.06	-0.16	-0.04	-0.15	0.25	-0.05	0.31	-0.27	-0.27	-0.01	0.15	0.50*	0.45*	1

Table 6: Elemental composition of soils

Soil series	Depth (cm)	Elemental composition (%)								LOI	CuO (mg/kg)	ZnO (mg/kg)	$CaCO_3$ (%)	Free Fe_2O_3 (%)
		SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O					
1.Allimadugu	0-9	71.5	15.6	10.25	0.04	0.15	0.12	0.68	1.23	5.24	150	20		3.64
	9-21	76.5	12.7	9.75	0.04	0.49	0.76	0.44	1.35	6.32	150	22		3.44
	21-38	73.2	13.9	10.75	0.04	0.61	0.96	0.11	0.98	6.62	180	22		4.26
	Ŵ	73.84	13.92	10.32	0.04	0.46	0.7	0.35	1.16	6.2	163.42	21.53	0	3.85
2.Venkateshswarapalem	0-15	70.4	14.8	12.5	0.02	0.56	0.62	0.01	0.76	4.32	60	15		4.77
	15-31	73.7	15	9.75	0.03	0.47	0.67	0.01	0.67	6.78	80	22		4.79
	31-53	69.8	14.9	13.5	0.04	0.53	0.79	0.01	0.94	7.34	90	25		4.28
	53-68	67.1	16.8	12.75	0.02	0.64	0.58	0.09	0.47	7.23	850	35	0.32	3.96
	68-92	66.7	21.9	11	0.04	0.65	0.57	0.09	0.56	6.87	930	55	0.15	3.63
	Ŵ	69.33	17.04	11.91	0.03	0.57	0.65	0.04	0.69	6.61	426.41	32.3	0.09	4.23
3.Venkatachalam	0-10	59.4	26.5	10.25	0.04	0.84	0.46	0.19	2.35	8.23	80	25		4.83
	10-22	57.3	24.3	14.5	0.05	0.33	0.38	0.25	3.46	8.34	900	60		4.69
	22-41	63.5	16.1	15.5	0.04	0.19	0.37	0.29	4.57	9.26	600	50	0.02	5.71
	Ŵ	60.75	20.92	13.96	0.04	0.38	0.39	0.25	3.72	8.75	561.9	46.9	0.01	5.21
4.Saidapuram	0-11	61.8	16.5	9.75	0.02	0.36	0.34	0.21	1.98	7.35	510	50		4.76
	11-26	64.3	17.6	14.25	0.07	0.23	0.33	0.23	2.34	9.64	760	50		7.69
	26-36	60.3	20.8	15.75	0.06	0.4	0.36	0.26	3.42	12.37	630	65	0.12	7.04
	Ŵ	62.49	18.08	13.22	0.05	0.31	0.34	0.23	2.5	9.62	648	53.86	0.03	6.6
5.Kadivedu	0-13	66.3	15.9	14.75	0.06	0.39	0.62	0.12	2.11	18.48	920	50		5.46
	13-56	64.5	23	10.25	0.06	0.32	0.53	0.18	3.45	12.56	890	60		6.98
	Ŵ	65.01	20.99	11.52	0.06	0.34	0.56	0.16	3.07	14.23	898.48	57.17	0	6.55
6.Nellore	0-10	72.8	13.8	12.25	0.02	0.23	0.38	0.2	0.78	15.66	110	60		6.2
	10-30	60.5	16.73	12.5	0.02	0.25	0.43	0.21	0.56	13.38	120	42		7.04
	Ŵ	63.65	15.98	12.44	0.02	0.24	0.42	0.21	0.62	13.96	117.44	46.62	0	6.82

A high negative correlation between SiO_2 and Al_2O_3, indicating silica enrichment with aluminium content in samples. Similarly, moderate negative correlation SiO_2 with Fe_2O_3 (r=-0.43*) showing decreasing trends with increasing SiO_2. The negative relation of SiO_2 with Na_2O(r=0.59**), CuO(-0.48*) and ZnO(-0.58*) whereas Al_2O_3 and Fe_2O_3 have positve correlation with these oxides indicating that they were controlled by Fe/Al-clays.

The positive relation of CaO with MgO(r=0.61**) but negative with Na_2O and K_2O. The high positive correlation between ZnO and CuO(r=0.71**) is reported. The high correlations between metal(loid) contents and soil properties for soils with different parent materials is attributed to the pedogenic process.[67] The correlation coeffcients between Fe, Al, and tri-pentavalent element contents were the strongest among all soil properties. Aluminum and Fe are concentrated as oxides in soil during desilication and ferralitization. The Fe/Al oxide minerals incorporate and adsorb metal(loid)s during their formation in soils.[68] These soils indicate a significant loss of CaO/MgO, which implies that calcium/magnesium is leached from these silica-rich parts of the profile. The inconsistent distribution of K_2O is linked to mineralogical variations. The negative correlation of MnO with silica (r=-0.21) shows that manganese is leached during ongoing weathering. Na_2O has a weak positive correlation with Al_2O_3 and Fe_2O_3 but a negative one with SiO_2, suggesting that sodium is retained in silica-rich zones. The correlation matrix (Table 7) results show that Fe and Al accumulate as the soil weathers, while elements like Ca, Mg, Na, and K are more easily washed away from the soil complex, which is characteristic of lateritic weathering.[69]

Table 7: Correlation among elemental oxides of laterite associated soils

Elemental oxides	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	LOI	CuO	ZnO
SiO_2	1										
Al_2O_3	-0.75**	1									
Fe_2O_3	-0.43*	0.07	1								
MnO	-0.28	0.37	0.44*	1							
CaO	0.08	0.26	-0.31	-0.2	1						
MgO	0.51*	-0.31	-0.2	-0.08	0.61*	1					
K_2O	0.01	-0.03	-0.11	0.13	-0.52*	-0.59**	1				
Na_2O	-0.59**	0.48*	0.47*	0.62**	-0.34	-0.39	0.27	1			
LOI	-0.28	0.08	0.43*	0.32	-0.37	-0.17	-0.07	0.25	1		
CuO	-0.48*	0.45*	0.41*	0.58*	-0.12	-0.2	-0.06	0.47*	0.31	1	
ZnO	-0.58*	0.43*	0.47*	0.43*	-0.42*	-0.44*	0.01	0.54*	0.64**	0.71**	1

Molar ratios and Weathering indices

Table 8 shows molar ratios and weathering indices of laterite associated soils of Nellore. The molar ratios of SiO_2 to R_2O_3 reveal a downward trend in all profiles, except for P1, which indicates a slight increase in the B horizon. This ratio ranges from 2.89 (P4) to 6.86 (P1), with higher values found in the Ap horizons compared to the B horizons. Based on the weighted means of the SiO_2/R_2O_3 ratio, the soils are ranked in ascending order as P1 (6.13) > P6 (4.93) > P2 (4.85). The weighted means for the molar ratio of Al_2O_3/Fe_2O_3 range from 9.05 (P1) to 7.4 (P6), while SiO_2/Fe_2O_3 varies from 19.05 (P1) to 5.36 (P5), and Al_2O_3/Fe_2O_3 ranges from 3.0 (P5) to 2.05 (P6). It is proposed that materials with an Fe_2O_3:Al_2O_3 ratio exceeding 1 and a SiO_2:Fe_2O_3 ratio below 1.33 be classified as 'ferruginous laterite'; while those with an Fe_2O_3:Al_2O_3 ratio below 1 and a SiO_2/Fe_2O_3 ratio also below 1.33 should be termed 'aluminous laterite'.[65] The depth functions of the molar ratios show irregular trends in all soils, except for Venkateswara Palem (P2), which exhibits a gradual decrease in SiO_2/R_2O_3 (from 5.24 to 3.92, Table 8) and SiO_2/Al_2O_3 (from 8.06 to 5.16). It is suggested that the molar ratio of Fe_2O_3/Al_2O_3 be greater than 1, while the SiO_2 to Fe_2O_3 ratio should exceed 10 to classify it as ferruginous laterite, as corroborated by the reddish-brown coloration of iron or aluminum oxides, oxyhydroxides or hydroxides, kaolinite, and quartz, characterized by a SiO_2:R_2O_3 ratio and subject to hardening upon exposure to alternating wetting and drying.[66]

The CIA of these laterite associated soils have value of 69.5 to 91.0 indicating intense weathering with serious losses of bases.[49] WIP shows similar trends of indicating intensive weathering with values of 2.0 (P6) to 6.35(P3) for MPWI, more than 75 of Kronberg A, 8.04 to 30.5 for Kronberg B indices and 8.79 to 37.41 for parker indices. For soils studied, the CIA values showed a strong and positive correlation with pedogenic iron index (R^2= 0.84**) and clay content (R^2 = 0.86**). These relationships indicate that CIA could be a useful weathering index for assessing weathering intensity and impart red to reddish brown B horizons under well drained and low organic carbon conditions that favour hematite formation.[67] The studies on correlation (**Table 9**) reveal a very strong positive correlation between the molar ratio of silica to sesquioxide and SiO_2/Al_2O_3 (r=0.98**) and Korenberg A (r=0.93**). There is also a significant correlation between Kornberg -A and PI (r=0.92**), alongside a high positive correlation between CIA and WI (r=0.86**). Conversely, a very high negative correlation is observed of CIA with PI (r= -0.92**).

Table 8: Molar ratios and weathering indices of soils

Profile Number	Depth(cm)	SiO2/ R2O3	SiO2/ Al2O3	SiO2/ Fe2O3	Al2O3/ Fe2O3	MPWI	CIA	A	B	PI	WI	Fed/ Fet*100	MIA(R)	MIO	IOL
P1.Allimadugu	0-9	5.48	7.77	18.59	2.39	2.57	83.87	87.08	16.13	21.94	13.45	35.51	55.65	92.22	26.55
	9-21	6.86	10.24	20.81	2.3	3.71	79.34	89.87	20.66	22.18	12.75	35.28	49.82	88.07	22.69
	21-38	5.96	8.89	18.05	2.02	3.48	84.98	88.49	15.02	14.83	22.66	39.63	50.9	90.26	25.19
	Ŵ	6.13	9.05	19.05	2.2	3.34	82.84	88.59	17.06	18.84	17.35	37.28	51.68	90.03	21.43
P2.Venkateswara palem	0-15	5.24	8.06	15	1.85	2.56	88.53	87.37	11.47	10.22	35.69	38.16	50.61	93.35	27.94
	15-31	5.86	8.29	20	2.4	2.38	90.03	87.71	9.97	9.33	36.51	49.13	56.46	93.16	25.14
	31-53	5.04	7.94	13.9	1.72	3.01	87.51	87.23	12.49	12.31	29.95	31.7	48.58	92.6	28.92
	53-68	4.59	6.72	14.1	2.08	2.43	90.53	85.29	9.47	8.79	53.36	31.06	53.63	94.33	30.57
	68-92	3.92	5.16	16.32	3.16	2.35	91.96	81.64	8.04	9.54	50.42	33	62.98	94.61	33.03
	Ŵ	4.85	7.1	15.8	2.29	2.56	89.77	85.56	10.22	10.15	41.38	36.02	54.86	93.63	29.44
P3.Venkatachalam	0-10	3.02	3.76	15.31	4.06	4.71	84.55	77.23	15.45	27.81	14.47	47.12	65.29	90.54	30.71
	10-22	2.89	3.99	10.55	2.64	5.36	81.04	78.28	18.96	37.41	10.46	32.34	56.22	89.77	32.34
	22-42	4.11	6.64	10.82	1.62	6.35	69.5	85.84	30.5	47.85	6.51	34.26	43.49	85.36	19
	Ŵ	3.5	5.2	11.81	2.49	5.68	76.38	81.63	23.26	40.1	9.53	36.77	52.32	87.85	25.66
P4.Saidapuram	0-11	4.59	6.33	16.72	2.63	3.77	81.97	84.81	18.03	23.14	11.97	48.82	56.62	90.08	29.81
	11-26	4.06	6.16	11.91	1.93	3.79	81.67	84.47	18.33	26.39	12.4	53.96	50.31	91.05	33.13
	26-35	3.31	4.9	10.2	2.08	5.3	78.33	81.56	21.67	37.3	9.94	49.78	50.74	89.17	37.74
	Ŵ	4.03	5.89	12.98	2.19	4.17	80.91	83.63	19.09	28.17	11.63	51.27	52.46	90.26	33.27
P5.Kadivedu	0-13	4.43	7.05	11.93	1.69	4.04	81.11	86.07	18.89	23.89	13.76	37.02	46.92	90.44	31.61
	13-46	3.7	4.75	16.71	3.51	5.22	80.55	80.94	19.45	36.67	9.16	68.1	60.96	88.13	34.02
	Ŵ	3.91	5.4	15.36	3	4.89	80.71	82.39	19.29	33.06	10.46	59.31	56.99	88.78	33.23
P6.Nellore	0-10	5.7	8.89	15.92	1.78	2	88.76	88.47	11.24	11.73	26.58	50.61	49.93	94.25	26.35
	10-39	4.66	6.89	14.4	2.1	2.12	91.83	84.02	8.17	10.03	37.96	56.32	54.53	95.27	32.58
	Ŵ	4.93	7.4	14.79	2.02	2.09	91.04	85.16	8.96	10.47	35.46	54.86	53.35	95.01	30.97

Table 9: Correlations between molar ratio's and weathering indices of laterite associated soils in Nellore

molar ratio's and Weathering indices	SiO_2/R_2O_3	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3	MPWI	CIA	Kornberg-A	Kornberg-B	PI	WI	Fed/Fet	IOL
SiO_2/R_2O_3	1											
SiO_2/Al_2O_3	0.98	1										
SiO_2/Fe_2O_3	0.72	0.56	1									
Al_2O_3/Fe_2O_3	-0.44	-0.61	0.28	1								
MPWI	-0.59	-0.53	-0.51	0.2	1							
CIA	0.25	0.17	0.37	0.1	-0.88**	1						
Korenberg-A	0.93	0.97**	0.46	-0.7	-0.49	0.1	1					
Korenberg-B	-0.25	-0.17	-0.37	-0.1	0.88**		-0.1	1				
PI	-0.56	-0.51	-0.5	0.16	0.96**	-0.92**	-0.46	0.92	1			
WI	0.23	0.19	0.22	-0.08	-0.77**	0.86**	0.18	-0.86	-0.83	1		
Fed/Fet	-0.17	-0.23	0.08	0.31	0.09	0.01	-0.23	-0.01	0.14	-0.24	1	
IOL	-0.65**	-0.67**	-0.42*	0.33	0.05	0.23	-0.65**	-0.23	0.04	0.07	0.38	1

The Schellmann[70] triplot diagram (Fe_2O_3-SiO_2-Al_2O_3 plot Figure 2) reveals that the soils associated with laterite are characterized as siliceous laterite - Kaolinitised laterites. The extent of weathering was assessed using the Chemical Index of Alteration,[17] ranging from 69.5 (P3) to 90.3 (P2), respectively, signifying a pronounced degree of weathering, predominantly aligning towards the Al_2O_3 apex on the A-CN-K plot (Figure 3). The A-CN-K triangular diagram illustrates the effects of chemical weathering on laterite, marked by the dissolution of plagioclase and K-feldspar, resulting in the depletion of Ca, Na, and K, while simultaneously enriching Al, achieving CIA values exceeding 90 with continued weathering progression, and enhancing the Al_2O_3 at the apex, dominated by kaolinite, halloysite, and gibbsite. Within the examined soil profiles, the majority of regolith samples exhibited significant weathering, with the plots clustering closely at the Al_2O_3 apex, indicating the presence of phyllosilicate clay minerals.

In conclusion, MIA[52] is computed to evaluate the total loss of mobile elements compared to immobile elements. In contrast, Fedo[71] introduced MIA(O) and MIA(R) for oxidative (MIAO) and reducing weathering. Babechuk and Fedo[72] proposed five stages of weathering: incipient, intermediate, advanced, intense, and extreme, based on the depletion of Ca, Na, Mg, K, and ±Fe, the formation of 2:1 and/or 1:1 clay minerals, and the presence of Al and/or Fe (oxy)-(hydr)oxides. This is further analyzed through the Mafic Index of Alteration,[52] which quantifies the net loss of significant mobile elements (Ca, Mg, Na, K ± Fe) in relation to the major immobile elements (Al ± Fe). MIA(O) values range from 85.6 to 95.27, while MIA(R) varies from 43.49 to 65.29 (P3), indicating extreme leaching of the labile elements, with Fe retained via (oxy)(hydr) oxide formation.[72] Given that these soils exhibit high Fe values, and some Fe is retained as goethite, the average MIA(R) values of 43.69 to 65.29 (P3) suggest that only Mg is lost during advanced weathering (Table 8). The Index of Lateritization (IOL) was employed to delineate the state of advanced to extreme weathering. IOL values range from 19 (P3) to 37.74 (P4), respectively, indicating a matured stage of lateritization.

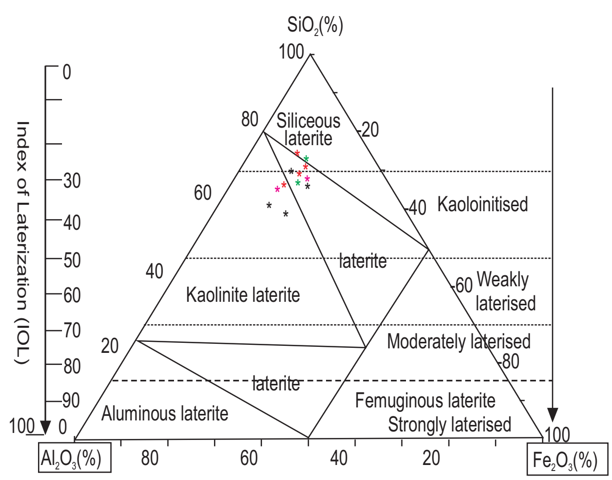

Figure 2: Ternary diagram of SiO_2-Al_2O_3-Fe_2O_3 showing index of laterization and stages of weathering

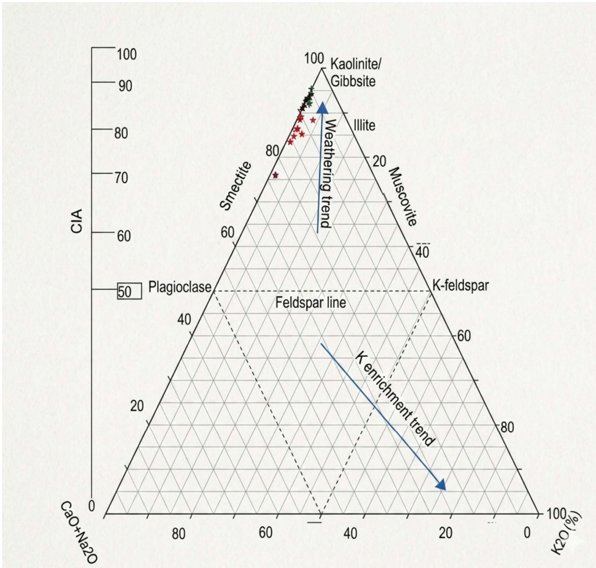

Figure 3: Ternary diagram of A-CN-K along with CIA

Grouping of soils using K mean clustering

Two clusters are formed based on centroids identified through a mix of 12 molar ratio parameters (4) and 8 weathering indices under study (Figure 4). KM is recognized as a vector quantization method, as it relies on the positions of points and their distances from each other. Cluster-1 consists of 10 horizons from Allimadugu (P1), Venkateswarapalem (P2), and Nellore (P6). This cluster has an average of 5.33±0.83 for SiO_2/R_2O_3, 7.89±1.4 for SiO_2/Al_2O_3, 16.71±2.52 for SiO_2/Fe_2O_3, and 2.18±0.42 for Al_2O_3/Fe_2O_3. The coefficient of variation is moderate, ranging from 15.02 for SiO_2/Fe_2O_3 to 19.28% for Al_2O_3/Fe_2O_3. Among the weathering indices, CIA, Korenberg-A, and IOL show low variability, while PI, WI, and Korenberg-B exhibit high variability, and MPWI and Fed/Fet have moderate variability.

In contratory, cluster-2 has 8 horizons of Venkata chalam(P3), Saidapuram(P4) and Kadivedu(P5). The mean molar ratios are :3.76±0.64 for SIO_2/R_2O_3, 5.45±1.26 for SiO_2/Al_2O_3, 13.02±2.77 SiO_2/Fe_2O_3 and 2.52±0.88 for Al_2O_3/Fe_2O_3.with moderate variability (Table 10) whereas low variability of CIA and Korenberg-A. The t test of two clusters performed to know statistical significance in mean differences regarding weathering indices and molar ratios.The results show that there is significant differences in means of these variables at 0.01 level except Al_2O_3/Fe_2O_3 (p =0.341), Fe_d/Ft(p =0.25) and IOL(p=0.18).On the other hand, cluster-2 includes 8 horizons from Venkata Chalam (P3), Saidapuram (P4), and Kadivedu (P5). The average molar ratios are: 3.76±0.64 for SiO_2/R_2O_3, 5.45±1.26 for SiO_2/Al_2O_3, 13.02±2.77 for SiO_2/Fe_2O_3, and 2.52±0.88 for Al_2O_3/Fe_2O_3, indicating moderate variability (Table 9). Meanwhile, CIA and Korenberg-A show low variability. A t-test was conducted between the two clusters to evaluate the statistical significance of mean differences in weathering indices and molar ratios. The results indicate significant differences in the means of these variables at the 0.01 level, except for Al_2O_3/Fe_2O_3 (p = 0.341), Fed/Ft (p = 0.25), and IOL (p = 0.18).

Table 10: Clustering of weathering indices in the soils

Cluster-1	SiO2/ R2O3	SiO2/ Al2O3	SiO2/ Fe2O3	Al2O3/ Fe2O3	MPWI	CIA	A	B	PI	WI	Fed/Fet	IOL
P1AP	5.48	7.77	18.59	2.39	2.57	83.87	87.08	16.13	21.94	13.45	35.51	26.55
P1B/A	6.86	10.24	20.81	2.3	3.71	79.34	89.87	20.66	22.18	12.75	35.28	22.69
P1BW	5.96	8.89	18.05	2.02	3.48	84.98	88.49	15.02	14.83	22.66	39.63	25.19
P2AP	5.24	8.06	15	1.85	2.56	88.53	87.37	11.47	10.22	35.69	38.16	27.94
P2B/A	5.86	8.29	20	2.4	2.38	90.03	87.71	9.97	9.33	36.51	49.13	25.14
P2Bt1	5.04	7.94	13.9	1.72	3.01	87.51	87.23	12.49	12.31	29.95	31.7	28.92
P2Bt2	4.59	6.72	14.1	2.08	2.43	90.53	85.29	9.47	8.79	53.36	31.06	30.57
P2Bt3	3.92	5.16	16.32	3.16	2.35	91.96	81.64	8.04	9.54	50.42	33	33.03
P6Ap	5.7	8.89	15.92	1.78	2	88.76	88.47	11.24	11.73	26.58	50.61	26.35
P6Bw	4.66	6.89	14.4	2.1	2.12	91.83	84.02	8.17	10.03	37.96	56.32	32.58
Mean	5.33	7.89	16.71	2.18	2.66	87.73	86.72	12.27	13.09	31.93	40.04	27.9
Standard Error	0.26	0.44	0.79	0.13	0.18	1.26	0.77	1.26	1.6	4.35	2.8	1.07

table cont....

Cluster-1	SiO2/ R2O3	SiO2/ Al2O3	SiO2/ Fe2O3	Al2O3/ Fe2O3	MPWI	CIA	A	B	PI	WI	Fed/Fet	IOL
Standard Deviation	0.83	1.4	2.51	0.42	0.56	3.98	2.43	3.98	5.05	13.75	8.86	3.38
cv(%)	15.64	17.71	15.02	19.28	21.22	4.53	2.8	32.43	38.56	43.04	22.12	12.11
						Cluster-2						
P3Ap	3.02	3.76	15.31	4.06	4.71	84.55	77.23	15.45	27.81	14.47	47.12	30.71
P3Bt1	2.89	3.99	10.55	2.64	5.36	81.04	78.28	18.96	37.41	10.46	32.34	32.34
P3Bt2	4.11	6.64	10.82	1.62	6.35	69.5	85.84	30.5	47.85	6.51	34.26	19
P4Ap	4.59	6.33	16.72	2.63	3.77	81.97	84.81	18.03	23.14	11.97	48.82	29.81
P4Bw1	4.06	6.16	11.91	1.93	3.79	81.67	84.47	18.33	26.39	12.4	53.96	33.13
P4Bw2	3.31	4.9	10.2	2.08	5.3	78.33	81.56	21.67	37.3	9.94	49.78	37.74
P5Ap	4.43	7.05	11.93	1.69	4.04	81.11	86.07	18.89	23.89	13.76	37.02	31.61
P5Bw	3.7	4.75	16.71	3.51	5.22	80.55	80.94	19.45	36.67	9.16	68.1	34.02
Mean	3.76	5.45	13.02	2.52	4.82	79.84	82.4	20.16	32.56	11.08	46.43	31.05
Standard Error	0.23	0.44	0.98	0.31	0.32	1.6	1.21	1.6	3.05	0.92	4.18	1.92
Standard Deviation	0.64	1.26	2.77	0.88	0.91	4.52	3.42	4.52	8.63	2.6	11.83	5.43
cv(%)	16.99	23.05	21.31	34.91	18.91	5.66	4.15	22.41	26.5	23.49	25.47	17.51
t*ctitical	2.13	2.94	2.97	3.25	3.11	2.97	3.05	2.97	3.16	3.25	3.05	3.11
T statistics	0.83-2.31	3.89	2.92	-1.01	-5.88	3.87	3.01	-3.87	-5.65	4.69	-1.19	-1.43
pvlaue	0	0	0.01	0.34	0	0	0.01	0	0	0	0.25	0.18

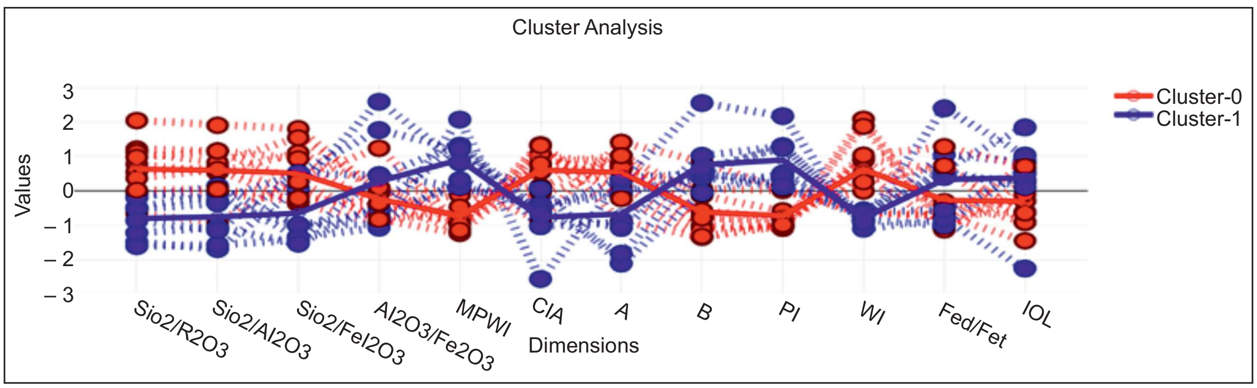

Figure 4: Clustering of molar ratios and Weathering indices of laterite associated soils

CONCLUSION

Six representative laterite-associated soil profiles in the Somasila project area of the Nellore schist belt were selected to study weathering intensity with morphological, physical, and chemical data. The Munsell notation was converted to a redness rating and the CIE Lab system was used to analyze the relationship between color components and physical and chemical data. There was a moderate correlation of redness (am) with clay and CEC, but a negative correlation with b values under both moist and dry conditions. These soils are slightly acidic to neutral, having Ca to Mg ratio of less than 3, suggesting an inhibition of phosphorus uptake and a decline in structural stability. Among the elemental composition, SiO_2 is dominant, qualifying them as siliceous laterite (as shown in the triplot diagram) with high molar ratios indicating non-lateritic characteristics. The Si-Al-Fe and A-CN-K triangular diagram illustrates the effects of chemical weathering on laterite, marked by the dissolution of plagioclase and

K-feldspar. The t-test of two clusters shows significant differences in the means of these variables at the 0.01 level, except for Al_2O_3/ Fe_2O_3 (p = 0.341), Fed/Ft (p = 0.25), and IOL (p = 0.18). According to this study on the weathering of laterite-associated soils, it was found that the Somasila project is sensitive to erosion risk and has physically degraded due to the alarming rate of quarrying laterite for construction work. Therefore, understanding the nature and properties of these soils provides pedogenic information to implement measures to prevent soil erosion and structural decline by increasing organic matter and soil permeability.

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